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SELECTION OF AN EFFICIENT DESALINATION TECHNOLOGY TO TREAT BRACKISH WATER FOR DOMESTIC APPLICATION IN METROPOLITAN CITIES IN INDIA USING MULTICRITERIA ANALYSIS

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ABSTRACT

This paper emphasizes the requisites of desalination plants in India. Effectual desalination technology is selected to treat brackish groundwater in metropolitan cities utilizing a case-study centered on Hyderabad. It presumes tremendous significance as it supplies drinkable water in metropolitan cities, all through the year. It is emerging as the chief challenges to the government on account of escalating population and frequent drought-like conditions. In the wake of this, unfiltered groundwater is utilized for direct consumption owing to the high costs of purification. Establishing desalination units to treat brackish water would augment conventional sources to supply drinking water at a low cost.

This paper proffers a model to select an effectual desalination technology by evaluating the numerous prevailing techniques utilizing MCE (multi-criteria evaluation). After consulting decision-makers, the experts in the desalination industry identify 9 criteria and 5 alternatives. Analytic Hierarchy course is ascertained as the suitable MCE technique where 5 alternatives are assessed by considering each criterion on expert's opinions. The results exposed that RO (reverse osmosis) is the most pertinent technology for the selected city followed by electrodialysis, vapor compression, multi-effect distillation and multi-stage flash in the decreasing sequence of priority.

***KEYWORDS:** Desalination, Brackish Water, Reverse Osmosis, MCE & Groundwater*

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Original Article

1. INTRODUCTION

Potable water, the most notable resource for the sustenance of life on this planet, is slowly becoming scarce. People all through the globe, since ancient times, never suffered from an insufficiency of secured water. In the report presented by the policies development together with studies branch of UN [1] it was indicated that, 1.2G(billion) individuals (i.e. almost 1/5 of global populace), are living in zones of physical water scarcity, whilst other 1.6Gindividuals (i.e. almost 1/4 of global populace) meet economical water deficiency. India, which is home to 16.00% of global populace, holds only4.00% and 2.50% of water area and terrain area respectively. As per Ernst and young report [2], out of the 1,869 TL [Trillion Litres] of water reserves in the country, only an estimated 1,122 TL is utilized owing to distribution issues together with topographic constraints. Demand for Water has risen steeply because of the steady population growth, growing urbanization, economic growth, and varying lifestyles. The potable water quality is a notable aspect in considering human health. Assurance of such quality is a base for the control and evasion of waterborne maladies. Safe potable water has a chief part in the overall comfort of the people. The freshwater emergency is already developed in numerous parts of India. Such crisis varies in intensity and scale at disparate times of the year. Actually, the country is speedily approaching a stage of exceedingly

hassled water availability state. Without managing fresh &safe water resources and their adequate supplies, socio-economic expansion simply cann't take place. It is assessed that around 10M people are in danger owing to surplus arsenic and about 70M(million)individuals of 20 states are in danger owing to surplus fluoride in the potable groundwater. Furthermore, increased concentration of nitrate, iron, chloride, and TDS (total dissolved solids) in groundwater is highly concerned for sustainable drinking water programmes. The continual population growth, frequently occurring droughts, economic development, together with other factors augmented the demand for freshwater. However, freshwater resources are very limited, and these limited sources are further declining due to salinity build-up, contamination, and overdraft. The government agencies are unable to render quality drinking water to the people of metropolitan cities in India all through the year owing to drought especially in summer. The people in and around metropolitan cities are depending on groundwater for their requirements without much attention on the quality of water as they could not treat brackish water on account of high costs implicated in desalination units. As per WHO(World Health Organization) [3] standards, water with TDS concentration below 500PPM is normally acceptable for the consumers, whilst acceptability may differ centered on circumstances. The natural resources for water could n't convene the ever-increasing requisites of potable water. This irregular distribution has forced humans to discover novel techniques for generating potable water. Numerous water utilities and municipalities now turned towards the development of alternate water sources like brackish inland waters, seawater, and immensely treated wastewater effluent. Desalination is the feasible solutions to augment potable water sources. It also enlarges and spread water supply portfolios. Desalination technology was established before 50 decennium and it could fill such gap but at the expenditure of high cost. A development of the latest enhanced technologies renders several opportunities for accessing potable water in numerous parts of the globe. Desalination, meaning salt removal brings the salinity of water from an extremely high PPM (35,000-45,000 PPM in sea water, up to10,000 PPM in earth's surface water) to the permitted limit of 500 -1000 PPM. It is regarded as the propitious options for facing the crisis of potable water. Wide research work is reported globally, but fewer attentions are paid in India to bring out suitable energy effectual desalination technologies to fulfill India's water needs for disparate applications. Central pollution control board and pollution controlling agencies presented the status reports which exposes that the groundwater as well the surface water is polluted in India.

The state governments want to utilize groundwater in metropolitan cities and supply quality water to the people by installing a desalination unit in respective areas which will be in operation for 3 to 4 months when water can't be supplied from the main source in summer and during drought. Such problems which are predominant in numerous parts of India are considered in this paper and Hyderabad city was chosen in the case study. The government agencies desired to implement desalination plants to filter ground brackish water and render quality water to the houses at lower cost at specific locations. As the plant has to operate only for 3 to 4 months, the criteria were selected grounded on the view of the decision maker. This paper renders a solution for these problems and suggests a model select suitable effectual desalination technology to treat brackish water and to supply them to the people during summer.

This paper initially proffers the desalination potential estimations in urban areas. The capital of Telangana, Hyderabad is chosen. Initially, the current water quality was assessed in and around Hyderabad by performing wide-field survey and by gathering reports from the literature. From those values, zones with water quality above 500PPM are recognized. Grounded on the population, the quantity of requisite of desalinated water is assessed for the identified areas. This analysis highlights the need for installing desalination unit to treat brackish water. The selection of suitable desalination technology for an enduse application is a simple or complex problem. The "viability" of desalination would be

devised in MCE background by finding the alternatives and criteria. 9 criteria are recognized centered on the views of decision makers. After executing wide literature survey, 5 alternatives were ascertained namely MED, MSF, RO, VC, ED. AHP (Analytic hierarchy process) was utilized to assess those 5alternatives by considering all criterion from the expert's opinions. Reverse osmosis was recognized as the best substitute for the given scenario followed by VC and ED.

2. OVERVIEW OF AVAILABLE COMMERCIAL DESALINATION TECHNOLOGIES

The problem is to ascertain the finest desalination technology. Consequently, it is obligatory to recognize the commercial desalination technologies that are functioning globally. Desalination, meaning removal of salts to bring the salinity of water from an extremely high PPM (35,000-45,000 PPM in sea water, up to10000 PPM in earth's surface water) to the permitted limit of 500 PPM or low which requires significant energy quantity. The commercial desalination process is categorized into 2 types: i) phase change thermal process and ii) membrane process [4] as exposed in figure 1.

2.1. Thermal Methods

All the thermal methods are grounded on the simpler working principle. The dissolved gases and the water are volatile on boiling saline water, whilst the dissolved salts and the minerals not evaporate until the boiling temperature is above 300^o C [5]. There are numerous distillation methods available which differ in the technology and application cost**.** The most vital thermal processes embrace MED and MSF.

2.1.1. MSF

In this process, the sea water is heated to 90°C – 120°C utilizing the heat of vapor condensation and the external steam. The heated seawater flashed in succeeding stages is sustained at declining pressure levels. The vapour formed is condensed and then regained as pure water. MSF generates distilled water of better quality for process industries, power plants industries together with other purity applications [6]. MSF remains to have an ample market share amid the 1sthalf of 21st centenary [7]. Abdel Nasser [8] introduced techno-economic exploration of long tube MSF for more capacity desalination units

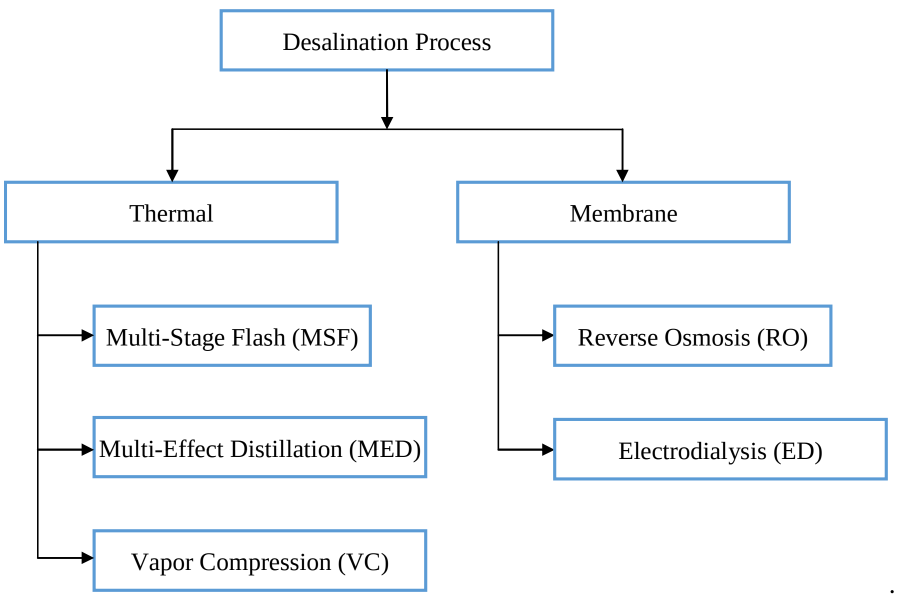

Figure 1: Classification of Desalination Technologies

2.1.2. MED

In MED (multiple effect distillation) methodologies, the water in the boiler is heated and is transmuted to hot steam. This hot steam heats the salty water in the 1st evaporator. The vapor emerged from this evaporator work as a heating medium for the 2nd evaporator and it boils the salty water there. Such like, the vapor emerged from the 2nd evaporator boils the salty water of 3rd evaporator. The boiling salty water, at the 3rd evaporator, works as a condensing medium for the 2nd evaporator vapor and the 2nd evaporator works as a condenser for the first evaporator vapor [9]. In this methodology, a large latent heat vapor condensation is reutilized numerous times before releasing it to the surroundings. Yongqing Wang et al [10] offered an economic and thermal performance analysis of multi-effect low-temperature evaporation in water desalination units. Hoseyn Sayyaadet al [11] introduced an economic design centered onenergy. The MED is an established technology with numerous installations which are in operation globally on account of its reliability, robustness, and scalability of the process and needs minimal treatment contrasted to the RO process.

2.1.3. Vapor Compression

The other thermal method utilized is the VC (vapor compression) method, which can have a multiple or single effect. The vapour in the evaporator is passed on to a vapor compressor. Then the vapor pressure as well the saturation temperature is elevated in the compressor. Thus, the compressed distillate vapor is utilized to force the evaporation course in the same phase at which it was generated, whilst itself condensing at the elevated saturation temperature correspondent to the compressor discharging pressure. There are 2 chief VC processes namely i) MVC (mechanical VC) and ii) TVC(thermal VC) processes [9]. Jiubing Shen et al [12] proffered a comprehensive examination of MVC single effect desalination units utilizing water injected twain screw compressors and ascertained that it is the propitious technology for water production of capacities < $600m^3/d$. H.M. Ettouney et al[13] explored that MVC is extremely competitive and attractive for the production of water with capacities <$5000m^3/d$.

2.2. Membrane Process

This process utilizes membranes to isolate fresh water from salty feed water. Feed water is poured on the surface of a membrane, which only passes water and eliminates salts. ED (electrodialysis) and RO are replacing desalting phase-change technologies for distributing water to an island and coastal communities all through the world. RO is an economical choice for the traditional water softening process. Mahmoud Shatat et al proffered disparate membrane types utilized in the desalination [14].

2.2.1. Reverse Osmosis

The desalination process by RO is grounded on the utilization of semi-permeable membranes. Those membranes pass only water and hence eliminate salts. It is notable that the constant enhancements in commercial RO membrane features and the numerous effectual systems to regain energy from the elevated pressure brine stream in seawater. RO units made RO, the utmost energy effectual methodology for seawater desalination currently available. The process RO is compact when contrasted to the thermal process. With the establishment of those membranes, lesser energy consumption drives improvements in this process. Baltasar Peñate et al[15] proffered an inclusive review of the present trends and future scenario in the model of seawater RO. Gasmi [16] considered the optimization of energy consumption in an RO desalination unit which holds a capacity of $30,000m^{3/}$day.

2.2.2. Electro-Dialysis

ED is an electrochemical separation process that encompasses electrically charged ion exchange membranes with an electric potential difference as a driving force. Membranes are constructed for passing anions/cations. In a variant ED process, termed EDR (electro-dialysis reversal), the electrodes' polarity is reversed regularly for reversing the flow direction, thereby inhibiting scale deposition together with fouling and rendering a self-cleaning method. Mohtada Sadrzadeh et al[17] proffered analysis on ED cell and ascertained to be very effectual for seawater desalination specifically at lesser concentrations. A.H. Galama et al[18] explored the appropriateness of ED in seawater desalination and ascertained the energy losses in electro dialysis.

3. ASSESSMENT OF BRACKISH WATER IN AND AROUND HYDERABAD

There are numerous areas in and around Hyderabad with high TDS in groundwater. The water quality is gauged from various reports and literature [19-24] and is proffered in table 1. The quantity requirement of desalinated water is also proffered in table 1 for certain areas just to accentuate the need of desalination unit. From table 1, it is observed that there are numerous areas with high TDS in water and the people are utilizing brackish water without treating it owing to high desalination costs. The people are utilizing these brackish waters from bore wells when they don't receive water from conservative sources. This analysis is a sample to accentuate the need for desalination set up at respective locations. The minimal water consumption is 12 liters/person which are utilized for cooking and drinking. The quantity of water required for this minimum consumption is varying from a minimum of 27m^3 to a maximum of 2701m^3 contingent on the location and population. The quantity may raise contingent on the requirement.

Table 1 proffers a suggestion on the problem of brackish water in one metropolitan city. If the analysis is done all through India, there will be numerous areas. These problems are predominant in all through India. The people are utilizing groundwater during summer without treating brings health problems. The subsequent section presents the methodology for the selection of effectual desalination technology.

Table 1: Quality and Quantity of Water in and Around Hyderabad [19, 20, 21, 22, 23, 24,]

Area In and Around Hyderabad	TDS(mg/L)	Population	Desalinated Water Per Person Per Day(litres)	Total Desalinated Required (m^3)
Patancheru	4018	117252	12	1407
Nagaram	1409	30502	12	366
Nacharam	2707	80000	12	960
Shameerpetvillage	1408	6900	12	82
Perizadiguda	1250	12737	12	152
RTC Colony	1820	6000	12	72
Paravathapuram	2410	2484	12	29
Muthyalaguda	2175	2500	12	30
Pratap singaram	2250	2215	12	26
Balapur	540	3500	12	42
Jeddimetla	540	6500	12	78
Tarnaka	575	4500	12	54
Abdullapurmet	1100	2674	12	32
Cherlapally	670	5578	12	66
Turkayamjal	1200	2250	12	27
Jawaharnagar	1300	44562	12	534
Rampally	1200	6019	12	72
Dayara	1100	2722	12	32
Kurmalguda	1150	1028	12	12
Qutubullapur	1200	225116	12	2701

4. COMPLEXITIES IN A SELECTION OF DESALINATION TECHNOLOGY

The choice of selecting the finest desalination technique for a specific application is extremely intricate, as the total availability of desalination technologies is overwhelmingly high and all technique stands suitable for numerous end-user applications. Therefore, to measure the intricacies implicated in the selection of a desalination technology for a specific application, a study is conducted for the selected city, Hyderabad and its desalination requirement is analyzed and proffered in table 1. The Hyderabad consists of areas which contain excessive brackish water varying from 500PPM-4000PPM. The people are utilizing this brackish groundwater in summer and drought without considering the quality. The government desires to establish desalination units and treat brackish water and distribute to people when they couldn't supply from conservative sources. Though the amount of water requirement varies from $27m^3$ to $2700\ m^3$, the range for the present problem is fixed from $27m^3$-$500m^3$. So there is a requisite to identify an effectual desalination technology to cater above problem which has to treat 500PPM-4000PPM and for a population of 5000-50000 to treat $27m^3$ to $500m^3$.

4.1. Desalination Technology Selection Problem in MCE Environment

The steps encompassed for selecting the finest appropriate desalination technology from the prevailing alternatives in MCE is exposed in figure 2[25]. The succeeding section illustrates those steps in detail and accentuates the role performed by those steps in decision making.

Figure 2: Decision Methodology for MCE Environment

The selected alternatives are 'MSF, MED, VC, RO & ED' and they are signified in the analysis as 'A1, A2, A3, A4 & A5' respectively. As the decision directly reliant on the facets that affect the problem, the decision criterion is to be picked carefully. where 'n' is the number of criteria to be considered.

5. SELECTION OF CRITERIA

After consulting with decision-makers and experts, the succeeding criteria are ascertained for this problem.

Life Time(C1): Technology's lifetime until the key replacement.

Water Recovery or Recovery Ratio(C2): Product water relative to the inputted water flow.

Freshwater Quality Required(C3): Salinity of the product water can alter the number of phases in the desalination process, the extent of pre-treatment required, and ultimately the final freshwater cost.

Consumption of Energy(C4): total energy consumed per liter.

Plant Cost(C5): The actual cost of desalting equipment varies significantly betwixt disparate manufacturers and

processes. The technical requirements of the unit and the capacity of equipment supply increase the costs of freshwater production.

Site Costs(C6): Land costs are a major detriment of the location preference. The cost of transporting water to its demand point is essentially considered. If the produced water transported to long distances i.e. to its consumption point, this effectually increases the unit cost of desalted water.

Availability of Skilled Labor(C7): It affects the plant cost. In case if the local labor is unavailable, it has to be imported and thus the fresh water costs and plant operation costs increases.

Disposal of Rejected Brine(C8): Brine disposal adds to the fresh water cost, as it must be treated in numerous cases.

Flexibility in Operation Start-up and Shut-Off(C9): This is a notable criterion in the present problem, as the plant has to be operated for 3 to 4 months.

5.1. Selection of Analytic Hierarchy Process for Evaluation

The presence of disparate characteristics in all MCE problems stimulated the evolution of numerous disparate aggregation methodologies. This methodologies embrace PROMETHEE (‘preference ranking organization method for enrichment evaluation’), weighted sum, multi-attribute utility theory, TOPSIS (a technique for an order of preference by similarity to ideal solution), AHP, disparate ELECTRE methods, fuzzy logic-centered methods, multi-objective programming, etc. The existent of numerous methods is also detrimental in choosing which a multi-criteria task is. After rigorous literature reviews, it was perceived that PROMETHEE, AHP, and TOPSIS were the widespread outranking techniques for the technology selection problem on account of their understand-ability, plausibility, and the ability to tackle qualitative criterion [26]. As there is insufficient quantitative data and intricacy of the problem, AHP method is utilized for examining the current problem. It is an MCDM method (‘Multi-criteria decision making’) centered on the priority theory. It handles intricate problems that entail the consideration of multiple criteria/alternatives simultaneously. AHP is capable(a)to integrate judgements and data of experts into design in a logical way,(b)to render a scale for gauging intangibles and methodology of establishing priorities,(c) to handle interdependence of system constituents,(iv) to permit revision of judgements in less time, (v)to observe the consistency in the decision maker’s judgements and (d)to hold group judgements, if the groups can’t get a natural consensus, makes this methodology a notable contribution in the MCDM field. This methodology is capable (a) to break down a intricate, unstructured scenario into its components (b) to arrange those parts into a hierarchical order (‘criteria, sub-criteria, alternatives’), (c) to assign numeric values from 1 - 9 to subjective judgements on the RI of all criteria grounded on the characteristics as proffered in table2. (d) to create judgments to find the total priorities of criteria/sub criteria/alternatives [27]. Preferences of AHP are found by pairwise comparisons, which embraces the assessment of elements together with all the other elements at provided hierarchical level.

$$[a_{ij}] \; where \; i,j = 1,2, \dots \dots \dots n$$

$$a_{ij} = 1 \; for \; i = j$$

$$a_{ij} = \frac{1}{a_{ji}} \; for \; i \neq j$$

The total number of comparisons necessary = $n(n-1)/2$.

5.1.1. Saaty's Method

It is a method of normalized arithmetical averages. The prepared pairwise CM(comparison matrix) is normalized. As a result of the normalized matrix, A is transmuted into normalized matrix B = [b_{ij}]. The elements of B matrix are computed according to the formula.

$$b_{ij} = \frac{a_{ij}}{\sum_{i=1}^{n} a_{ij}} \quad (1)$$

Calculating the preferences betwixt the elements under investigation eigenvector w = [Wi] is performed by computing the arithmetic averages from the row of the normalized CM. The components of this vector are computed grounded on the formula,

$$w_i = \frac{\sum_{j=1}^{n} b_{ij}}{n} \quad (2)$$

The priorities of the criteria are assessed by determining the principal eigenvector w of the matrix A which is given as,

$$Aw = \lambda_{max} w \quad (3)$$

When the w vector is normalized, it turns into the vector of priorities of criteria concerning the goal. λ_{max} is the highest eigen value of matrix A, and the equivalent vector w comprises only positive entries. The consistency of the judgemental matrix is ascertained by a measure called CR (consistency ratio), formulated as

$$CR = \frac{CI}{RI} \quad (4)$$

Where, CI - consistency index and

RI - random index.

CI is formulated as

$$CI = (\lambda_{max} - n)/(n - 1) \quad (5)$$

Prof Saaty gave a gauge for consistency as CI defined as a deviation or degree of consistency utilizing the formula

If the CR $\leq$10%, the inconsistency is satisfactory. If the

CR > 10%, the subjective judgment is needed to be revised.[29]

5.2. Estimation of Weights for the Criteria

For analyzing the alternatives in respect of criteria, RI ('relative importance') of the criteria in respect of one another (i.e. pairwise) is to be assessed. As the literature doesn't proffer the details of RI, here, the priorities for the criteria are synthesized by utilizing the Saaty's nine-point scale as signified in a table of RI which is mentioned in Table 2[28].

All criteria are compared pairwise with the other and the RI value was attained. Here, each criterion is pairwise contrasted by 5 decision makers and the mean values of their responses are tabulated in table 3. By utilizing Eigenvector and power methods, the relative weights of criteria are computed and presented in table 4

Table 2: Saaty's Nine-Point Scale of Relative Importance

Stage of Scale	Definition	Characteristics
1	Equal Importance	2 activities contribute evenly
3	Moderate importance of one over another	Judgment and Experience reasonably favor one activity over another
5	Strong importance	Judgment and Experience solidly favor one activity over another
7	Very strong importance	An activity is solidly favored and its dominance illustrated in practice
9	Extreme Importance	The evidence favoring one activity over another is of the highest probable order of affirmation
2,4,6,8	Intermediate values betwixt the two adjacent judgment	As compromise is needed
Reciprocals	-	If activity 1 has one of the above numbers assigned to it when compared with activity 2, then activity 2 has the reciprocal value when compared with activity 1. Thus, the lowest limit in the scale is 1/9 being reciprocal of 9.

Table 3: Matrix on the Relative Importance of Criteria

	C1	C2	C3	C4	C5	C6	C7	C8	C9
C1	1	5	3	1/5	1	1/3	9	5	1
C2	1/5	1	1/3	1/5	1/5	1/5	7	5	1/7
C3	1/3	3	1	1/3	1/5	1/7	5	5	1/5
C4	5	5	3	1	1	1/5	9	7	1/3
C5	1	5	5	1	1	1	3	3	1
C6	3	5	7	5	1	1	7	9	1
C7	1/9	1/7	1/3	1/9	1/3	1/7	1	3	1/5
C8	1/5	1/5	1/5	1/7	1/3	1/9	1/3	1	1/5
C9	1	7	5	3	1	1	5	5	1

Table 4: Relative Weights of Criteria

Criteria	Relative Weights
C1	0.1260
C2	0.0504
C3	0.0582
C4	0.1584
C5	0.1324
C6	0.2346
C7	0.0282
C8	0.0202
C9	0.1790

5.3. Application of AHP Evaluation for Selecting Best Desalination Technology for Metropolitan Cities to Treat Brackish Water

Figure 3 presents the structure of the hierarchy. Level 1 match to the objective of the finest desalination. Level 2 to the criteria (C1 to C9) and level 3 to the desalination technologies (A1 to A5). Numerous experts from the desalination industry and water board were consulted in to form disparate pairwise CMs. Preferences centered on Saaty's scale for every 9 criteria at the 2nd level in respect of the goal of selecting the finest desalination system is already proffered in table3. 36 comparisons are requisite on Saaty's scale. This is grounded on the size of the pairwise CM- N X N i.e., N(N-1)/2 where N= 9.Amongst 81 elements/responses, the value of 8diagonal elements are of 1.Amongst the other available 72 elements, the values of 36 elements are merely reciprocal of the other 36, grounded on the reciprocal theorem.

Suchlike, preferences of 5 desalination technologies at the 3rd level in respect of each criterion at the 2ndlevel requires10 pairwise comparisons. This is grounded on the size of the pairwise CM- N X N i.e., N(N-1)/2 where N =5. Amongst 25 elements (5 X 5 matrix), the 5 diagonal elements are of value 1. Amongst the other existent20 elements, the value of the 10 elements is merely reciprocal of the other 10 elements. Grounded on the expert's opinions, the matrix for pairwise comparisons of the disparate technologies in respect of priority vector and each criterion are proffered in tables 5-23. The priority vectors and normalization are computed utilizing equations 1 & 2. Table 22 presents a final matrix with priority vectors of alternatives in respect of each criterion, relative weights of criterion and methodology to compute the final vector. By utilizing the weighted sum model, the final weights of alternatives in respect of each criterion are computed and are proffered in table 24. The subsequent step is to compute the CR to gauge how reliable the judgments are relative to huge samples of merely random judgment. If CR > 0.1 the judgments are unreliable as they are extremely close from comfort to randomness and the implement is valueless and to be repeated. The CR is found utilizing equations 3,4,5 Table 25 proffers the CR of alternatives in respect of each criterion.

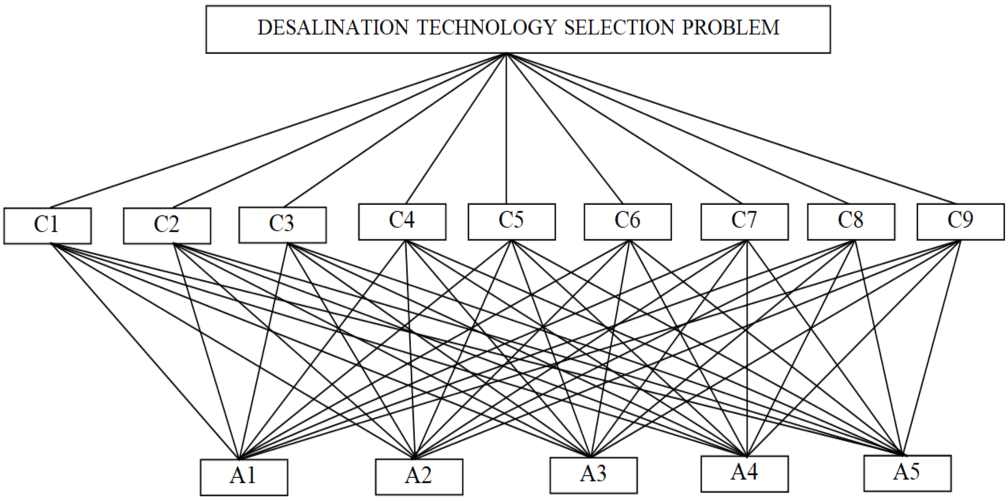

Figure 3: Decision Hierarchies of Desalination Technologies

5.4. Comparison of Results

The outcome of the analysis indicates that the most notable criteria for selecting desalination technology for the given problem are the site cost with the relative weight of 0.2346 followed by the flexibility in start up and shut off period with a relative weight of 0.1790 followed by the consumption of energy with 0.1584.RO is considered as the finest desalination to the present problem. The ED is the next best technology followed by VC, MED, and MSF. If the consistency ratio is less than 10%, it specifies that human judgment is consistent. Table 25 presents the consistency ratio for the alternatives in respect of each criterion. In the present problem, the CR is < 0.1 in all scenarios and hence it specifies that human judgement is consistent.

Table 5: Pairwise Comparisons Matrix of Desalination Technologies for Lifetime

	A1	A2	A3	A4	A5
A1	1	1	7	7	7
A2	1	1	7	7	7
A3	1/7	1/7	1	3	1
A4	1/7	1/7	1/3	1	1/3
A5	1/7	1/7	1	3	1

Table 6: Priority Vector Matrix of Alternatives with Respect to Life Time

A1	0.402
A2	0.402
A3	0.076
A4	0.041
A5	0.076

Table 7: Pair Wise Comparison Matrix of Desalination Technologies with Respect to Water Recovery

	A1	A2	A3	A4	A5
A1	1	1	1	1/9	1/9
A2	1	1	1	1/9	1/9
A3	1	1	1	1/7	1/7
A4	9	9	7	1	1
A5	9	9	9	1	1

Table 8: Priority Vector Matrix of Alternatives with Respect to Water Recovery

A1	0.049
A2	0.049
A3	0.0548
A4	0.422
A5	0.422

Table 9: Pairwise Comparison Matrix of Desalination Technologies with Respect to Treated Water Quality

	A1	A2	A3	A4	A5
A1	1	1	1/3	1/5	1/5
A2	1	1	1/3	1/5	1/5
A3	3	3	1	1/3	1/5
A4	5	5	3	1/3	1
A5	5	5	5	3	1

Table 10: Priority Vector Matrix of Alternatives with Respect to Treated Water Quality

A1	0.058
A2	0.058
A3	0.132
A4	0.288
A5	0.461

Table 11: Pair Wise Comparison Matrix of Desalination Technologies with Respect to Consumption of Energy

	A1	A2	A3	A4	A5
A1	1	2	1/7	1/9	1/9
A2	1/2	1	1/5	1/7	1/7
A3	7	5	1	1/3	1/5
A4	9	7	3	1	1/3
A5	9	9	5	3	1

Table 12: Priority Vector Matrix of Alternatives with Respect to Consumption of Energy

A1	0.0447
A2	0.0352
A3	0.152
A4	0.2720
A5	0.3640

Table 13: Pair Wise Comparison Matrix of Desalination Technologies with Respect to Plant Cost

	A1	A2	A3	A4	A5
A1	1	1/3	1/5	1/9	1/7
A2	3	1	1/3	1/7	1/5
A3	5	3	1	1/5	1/3
A4	9	7	5	1	3
A5	7	5	3	1/3	1

Table 14: Priority Vector Matrix of Alternatives with Respect to Plant Cost

A1	0.0347
A2	0.0676
A3	0.1343
A4	0.5029
A5	0.260

Table 15: Pair Wise Comparison Matrix of Desalination Technologies with Respect to Site Cost

	A1	A2	A3	A4	A5
A1	1	1/3	1/5	1/9	1/7
A2	3	1	1/7	1/7	1/9
A3	5	5	1	1	1
A4	9	7	1	1	3
A5	7	9	1	1	1

Table 16: Priority Vector Matrix of Alternatives with Respect to Site Cost

A1	0.0385
A2	0.057
A3	0.267
A4	0.317
A5	0.319

Table 17: Pairwise Comparison Matrix of Desalination Technologies with Respect to the Availability of Skilled Labor

	A1	A2	A3	A4	A5
A1	1	1/5	1/3	1/7	1/5
A2	5	1	1/3	1/7	1/5
A3	3	3	1	1/3	1/3
A4	7	7	3	1	1
A5	5	5	3	1	1

Table 18: Priority Vector Matrix of Alternatives with Respect

A1	0.046
A2	0.094
A3	0.141
A4	0.361
A5	0.337

Table 19: Pair Wise Comparison Matrix of Desalination Technologies with Respect to Disposal of Rejected Brine

	A1	A2	A3	A4	A5
A1	1	1	1/3	1/3	1/5
A2	1	1	1/3	1/5	1/5
A3	3	3	1	1/3	1/5
A4	5	5	3	1	1/3
A5	5	5	5	3	1

Table 20: Priority Vector Matrix of Alternatives with Respect to Disposal of Rejected Brine

A1	0.06
A2	0.062
A3	0.135
A4	0.271
A5	0.381

Table 21: Pair Wise Comparison Matrix of Desalination Technologies with Respect to Flexibility in Operation Start-Up and Shut Off

	A1	A2	A3	A4	A5
A1	1	1	1/3	1/9	1/7
A2	1	1	1/3	1/9	1/7
A3	3	3	1	1/5	1/5
A4	9	9	5	1	3
A5	7	7	5	1/3	1

Table 22: Priority Vector Matrix of Alternatives with Respect to Flexibility in Operation Start-Up and Shut Off

A1	0.043
A2	0.043
A3	0.1
A4	0.504
A5	0.3016

Table 23: Final Priority Vector Matrix of Alternatives with Respect to Criteria and their Relative Weights

	0.126	0.054	0.0582	0.1584	0.1324	0.2346	0.02824	0.0202	0.179
	C1	**C2**	**C3**	**C4**	**C5**	**C6**	**C7**	**C8**	**C9**
A1	0.402	0.0495	0.058	0.0447	0.0347	0.0385	0.046	0.06	0.043
A2	0.402	0.0495	0.058	0.0352	0.0676	0.057	0.094	0.062	0.043
A3	0.076	0.0548	0.132	0.153	0.1343	0.267	0.1415	0.135	0.1
A4	0.041	0.422	0.288	0.2720	0.5029	0.317	0.361	0.27	0.504
A5	0.076	0.446	0.4615	0.3640	0.260	0.319	0.337	0.385	0.301

Final Matrix

0.126 X 0.402 + 0.0504 X 0.0495 + 0.0582 X 0.058 + 0.1584 X 0.0447 + 0.1324 X 0.0347 + 0.2346 X 0.0385 +

0.2825 X 0.046 + 0.0202 x 0.06 + 0.179 X 0.043 = 0.0873

Table 24: Final Ranking of Alternatives

A1	0.08743	5
A2	0.09602	4
A3	0.1492	3
A4	0.3312	1
A5	0.297	2

Table 25: CR for 5 Alternatives with Respective to Each Criterion

	Alternatives	λ_{max}	CI	CR
C1	A1,A2,A3,A4,A5	5.2	0.07	0.064
C2	A1,A2,A3,A4,A5	5.0	0.001	0.0013
C3	A1,A2,A3,A4,A5	5.3	0.087	0.087
C4	A1,A2,A3,A4,A5	5.3	0.085	0.075
C5	A1,A2,A3,A4,A5	5.3	0.090	0.080
C6	A1,A2,A3,A4,A5	5.1	0.049	0.043

Table 25: Contd.,				
C7	A1,A2,A3,A4,A5	5.4	0.100	0.089
C8	A1,A2,A3,A4,A5	5.1	0.047	0.0419
C9	A1,A2,A3,A4,A5	5.2	0.05	0.0416

6. CONCLUSIONS

In India the people near metropolitan cities are consuming brackish ground water without treating it in summer due to high cost of desalination technologies. Hyderabad is selected for case study and quality of water is evaluated in some places to emphasize need of desalination. AHP multicriteria method is used to evaluate viability of desalination technologies and accordingly following conclusions were made.

- Nine criteria and five alternatives affecting the desalination selection were identified.
- AHP was chosen to be the suitable technique for desalination technology selection and the evaluations were performed.
- Reverse osmosis is identified as the most viable desalination technology for given conditions
- This model can be applied to similar scenarios by slight change in Pay-off matrix.

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